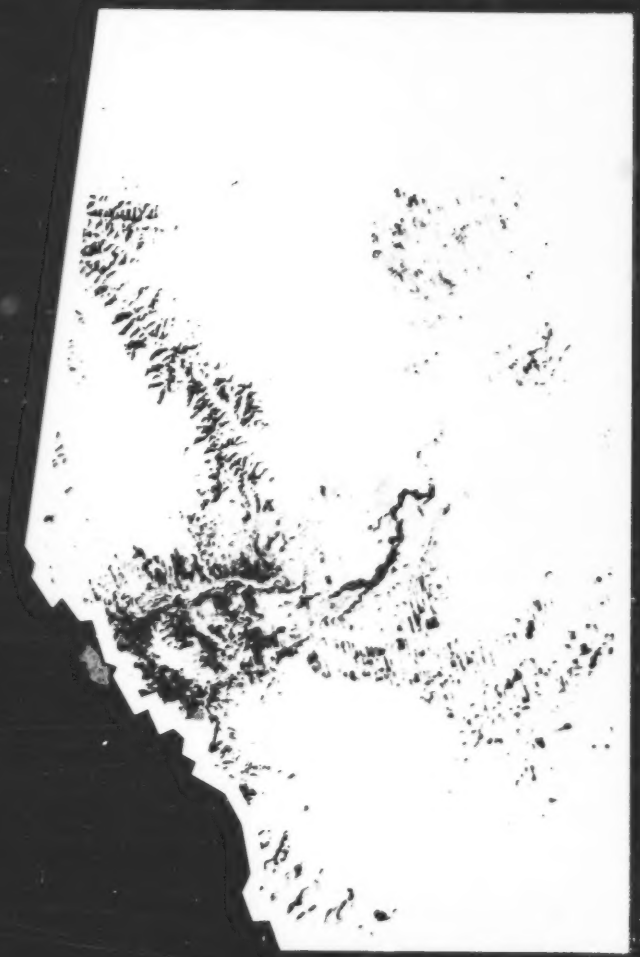
REMOTE SENSING

Wildlife Winter Range



Alberta
ENVIRONMENT

LANDSAT MAPPING OF SNOW COVER TO IDENTIFY CRITICAL WILDLIFE WINTER RANGE

By

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Demonstration Project

This is the abridged edition of a demonstration project report sponsored by the Alberta Remote Sensing Center, Alberta Environment. The complete report is available for in-Center study.

Cover Photograph

Effects of Chinook on snow cover in Southwestern Alberta.
Black and white rendition of Landsat C1 (20771-17354), 3 March, 1977.

ABSTRACT

This report shows Landsat imagery to be useful for identifying sites which are free of snow and possess little forest cover. Such sites represent potential critical winter habitat for native ungulates in the Rocky Mountain regions of North America. The technique demonstrated involved 1) the use of summer Landsat imagery for computer mapping of vegetation cover types; 2) computer geometric registration of a winter scene onto the summer scene; 3) computer mapping of snow cover on a winter scene; and 4) computer identification and mapping of the non-forested sites free of snow on the date of the winter image. Classification accuracy using this technique was 89%. Visual interpretation of Landsat photographic products, density slicing of any single Landsat band, and multispectral classification of a winter Landsat scene all gave much poorer accuracy results of between 48 and 65%.

CONTENTS

	PAGE
Acknowledgements	i
Abstract	ii
Contents	iii
List of Tables and Figures	iv
Introduction	1
Methods	1
Results	2
Visual Interpretation	2
Single Level Density Slicing	2
Multispectral Classification	6
Multitemporal Landsat Analysis	9
Conclusions	9
References Cited	11

LIST OF TABLES AND FIGURES

		PAGE
TABLE 1.	Landsat MSS digital values for surface features on a winter scene (3 March, 1977) in Kananaskis Country, Alberta	5
TABLE 2.	Euclidean distances between clusters from analysis of winter Landsat imagery (3 March, 1977)	5
TABLE 3.	Accuracy of multitemporal Landsat digital analysis for mapping non-forested winter snow-free sites in the Rocky Mountains of Alberta	10
FIGURE 1.	Location of study region in southwestern Alberta	2
FIGURE 2.	Landsat images of southwestern Alberta showing the effects of major chinook events on snow cover	3,4
FIGURE 3.	Cluster bounds for vegetation cover types identified on Landsat imagery (3 March, 1977). Band 4 vs Band 7	6
FIGURE 4.	Cluster bounds for vegetation cover types identified on Landsat imagery (3 March, 1977). Band 5 vs Band 6	6
FIGURE 5.	The South Sheep River grazing allotment showing the sequential steps required for mapping non-forested snow-free sites	7,8

1. INTRODUCTION

Snow cover, which regulates the availability of winter food supplies, is one of the most significant factors affecting the survival of native ungulates. Proper management of ungulate habitat therefore requires a knowledge of snow cover characteristics. It is important to know not only the location of winter snow-free areas but also site-specific variability in snow cover conditions in actual or potential winter habitat areas. Although snow cover is highly variable between sites, especially in the mountainous terrain of southwest Alberta, snow sorting by winds, influenced by local topography and snowmelt/ablation, follows regular yearly patterns in specific locations. It is possible to map a given area into units which reflect consistent relative dates of snowmelt and snow depths during the winter. Many workers have commented on the year-to-year consistency of relative snow-melt timing between different sites. The most significant of these is the work of Gjaerevoll (1950).

No work to date in North America has used Landsat imagery to monitor snow conditions following chinooks*. Golding (1974) began such a study in 1973 but a lack of cloud-free imagery prevented him from analyzing his study area shortly after a chinook period. Many studies have used Landsat imagery to monitor general snowline recession in the spring. Most notable of these past studies are those by Golding (1974), Gloersen and Salomonson (1975), Meier (1975), Katibah (1975), Foster and Rango (1975), and Draeger and Lauer (1974).

Alfoldi (1976) established that scenes with complete snow cover exhibit high correlations between all four Landsat bands. Total pixel brightness, therefore, is more important for snow cover analysis than for mapping of other surface features where band-to-band correlations are much lower, especially between the two visible bands and either of the two infrared bands. This high band-to-band correlation when an image is largely snow covered suggests that single band density slicing may be as valuable for mapping snow cover as multispectral cluster analysis. The work of O'Brien and Munis (1975) demonstrated that different types of snow cannot be differentiated in the red and near infrared portions of the spectrum. Thus Landsat bands 4 and 5 offer the greatest possibilities for single level slicing of different snow types. Research has shown that no feature of snow other than its areal extent can be accurately measured or mapped from Landsat imagery (Alfoldi 1976). Density, water content, depth, texture and structure of snow has not been accurately differentiated by any researcher.

A factor greatly affecting snowmelt and distribution patterns in southwest Alberta is winter "chinook" conditions. The meteorological characters of chinooks have been well documented (see Lester 1976 for a review of these studies). However, little, if any, work has been done on the effects of chinooks on snow cover. This present study was undertaken to determine whether Landsat imagery could provide data adequate for identifying and mapping snow cover conditions in the Rocky Mountains of Alberta. The study area includes the mountains and foothills of southwestern Alberta as identified on Figure 1. Many native ungulate species which require winter habitat are found in this region, including Rocky Mountain bighorn sheep (Ovis canadensis), mountain goat (Oreamnos americanus), wapiti (Cervus canadensis), mule deer (Odocoileus hemionus), whitetail deer (Odocoileus virginianus), and moose (Alces alces).

* chinook - a warm, dry wind that blows off the eastern slopes of the Rocky Mountains

2. METHODS

Four different analytical methods were used to test the capabilities of Landsat imagery for identification and mapping of critical snow-free winter range sites. The first involved the use of non-precision processed and unenhanced standard color composite Landsat images available from the Canada Centre for Remote Sensing, Ottawa. A search was made for available winter cloud-free Landsat images. Images potentially available for study were screened based on daily meteorological records for the Kananaskis, Banff, Cochrane and Calgary weather stations to identify images obtained immediately following major chinook events. Useful images were ordered as 1:1,000,000 scale color composites of band 4 (green visible light band with blue primary color filter), band 5 (red visible light band with green primary color filter) and band 7 (far infrared light with red primary color filter). Visual interpretation was conducted using an Old Delft scanning stereoscope.

The second, third and fourth analytical methods used radiometrically corrected Landsat digital data. The computer compatible tapes were in the format defined by Strome et al. (1975) and were processed using the CAL 2 linear radiometric calibration process (Ahern and Murphy 1978).

The second method involved single level density slicing of each of the four bands. A 3 March 1977 Landsat image (#20771-17351) was used for this analysis. High-flight color infrared photography obtained in 1975 (Roll #A37252, 8 September 1975) over large parts of the study scene was used to identify the ground cover types. This identification provided precise ground truth points for describing the features discriminated by the Landsat images. A 512 x 512 pixel subscene of the Sheep River drainage basin area was selected for analysis. This area exhibited the full range of cover types -- from bare, non-forested areas to dense forest cover.

The third method involved unsupervised cluster analysis of the four-band Landsat digital data for 3 March 1977. Analysis methodology used the migrating means algorithm described by Goldberg and Shlien (1976). Sixty control sites, obtained from the color infrared aerial photography and field sampled, were used to test the accuracy of this mapping procedure.

The fourth method involved the use of multi-date Landsat images. A summer scene (#21707-17460) was used to classify vegetation cover types for an intensive study area (see Figure 1) and a winter scene (#30399-17572) was geometrically corrected to directly overlay onto the summer scene. The winter scene was then classified using the migrating means unsupervised cluster algorithm to identify each picture cell on the image which had snow cover. The summer forest cover type clusters and winter snow cover cluster were combined into one class and logically subtracted from the remainder of the study image, leaving only those sites which were both non-forested and free of snow at the time of the winter Landsat image.

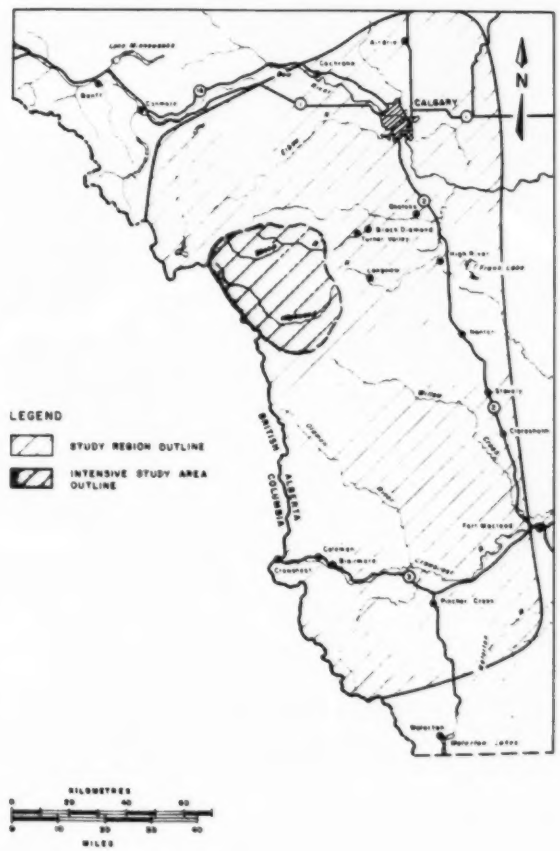


Figure 1 Location of study region in Southwestern Alberta.

3. RESULTS

3.1 Visual Interpretation

Figure 2 shows four of the seven Landsat color composites used in this portion of the study. These images allow for visual identification of large snow-free regions. However, inspection under high enlargement reveals that non-forested snow-free sites cannot be accurately distinguished from deciduous stands, mixedwood stands and some coniferous forest stands which possess snow cover in the understory.

Of 560 sites mapped visually as "non-forested and snow-free" using the 3 March 1977 Landsat photography product, 201 were sites which are predominantly or entirely forested. The classification accuracy is about 64% based on these commission errors. Ninety-eight of the forest sites contributing to this large commission error possess a canopy closure in the range from 36 to 65%.

Omission errors could not be assessed because of a lack of ground snow cover data for the date of the Landsat image analyzed. Omission errors probably do exist on sites which are actually bare of snow but made up of predominantly barren limestone or dolomite bedrock. These rock types are very light in color and are visually indistinguishable from snow cover on the photographic Landsat products.

3.2 Single Level Density Slicing

Table 1 lists the single band digital values for major surface feature types as recorded on the 3 March 1977 Landsat image of the study area. The upper and lower bounds of these digital values determine the spectral limits for each surface feature category. The surface feature types identified are 1) non-forested snow-free sites, 2) non-forested snow-covered sites, 3) cloud, 4) shrubland, deciduous, mixedwood and young coniferous forests, 5) forests with canopy closure <35% 6) lodgepole pine-spruce forest with canopy closure >35% 7) spruce-subalpine fir forest with canopy closure >35% and 8) cloud shadow. If single level density slicing is to be successful, overlap in digital values between the major features of interest must be quite low.

On this late winter Landsat scene, non-forested snow-free sites exhibit significant, if not complete, spectral overlap with at least four other surface feature types on each of the four MSS bands. The data in Table 1 shows that Landsat spectral response on non-forested snow-free sites overlaps in bands 6 and 7 for every surface feature type except spruce-subalpine fir forest and cloud shadow. Single level slicing of bands 6 and 7 will not allow for differentiation of non-forested, snow-free sites from any of the other surface feature types. In fact, complete spectral overlap with cloud and shrubland, deciduous, and mixedwood forest is seen for these sites in bands 6 and 7. Significant spectral overlap

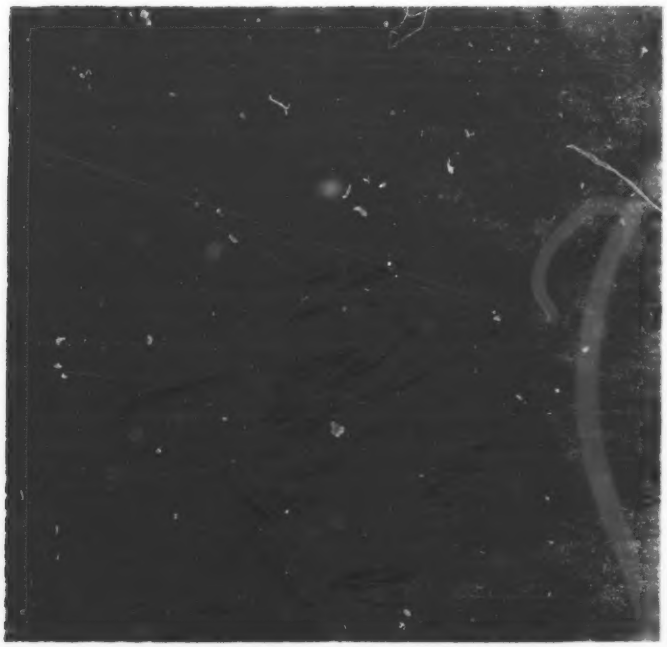


Fig. 2a 3 March, 1977.
Snow-melt area
Morley to Calgary.

Fig. 2b 3 March, 1977.
Snow-melt area
Crowsnest to
Fort MacLeod.

Figure 2 Landsat images of southwestern Alberta showing the effects of major chinook events on snow cover.

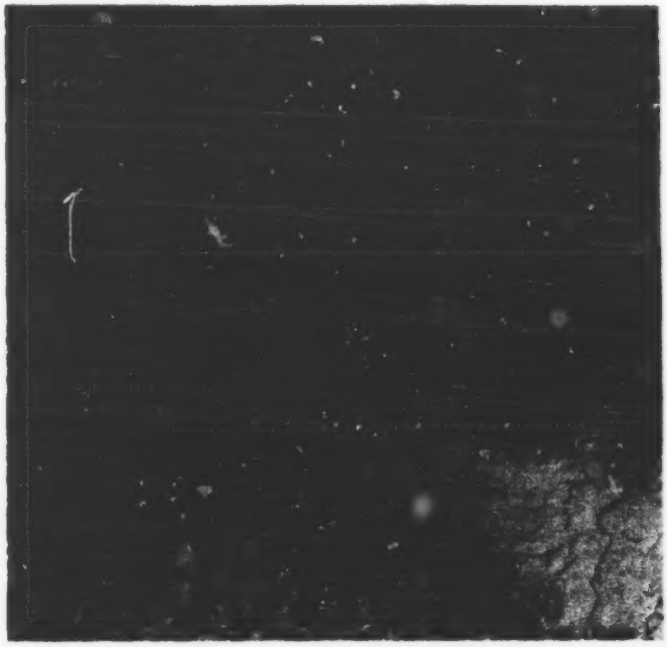


Fig. 2c 28 November, 1977. Snow-melt area due east of Porcupine Hills.

Fig. 2d 20 February, 1974. Snow-melt area due east of Porcupine Hills.

TABLE 1. Landsat MSS digital values for surface features on a winter scene (3 March 1977) in Kananaskis Country, Alberta.

Surface Feature Type	Landsat Digital Value (0-63 scale) Band 4 ($\bar{x}$ / Range)	Band 5 ($\bar{x}$ / Range)	Band 6 ($\bar{x}$ / Range)	Band 7 ($\bar{x}$ / Range)
Non-forested; snow-free	10.7 / 9.1-11.2	11.7 / 10.8-13.2	16.6 / 14.2-18.3	17.5 / 15.2-20.3
Non-forested; snow cover	42.9 / 11.1-63.0	44.4 / 12.1-63.0	45.1 / 15.2-63.0	37.8 / 15.2-63.0
Cloud	35.1 / 8.3-63.0	34.3 / 12.1-63.0	33.4 / 6.0-63.0	32.9 / 4.0-63.0
Shrubland/deciduous and mixedwood conifer forests	12.5 / 9.0-15.3	12.5 / 9.0-18.3	15.0 / 10.0-22.3	12.0 / 6.0-15.2
Sparse conifer forest (cover <35%); snow visible in understory	8.4 / 7.1-10.2	8.0 / 6.0-9.2	14.9 / 13.1-17.3	15.9 / 13.1-18.3
Lodgepole pine-spruce forest (cover >35%)	8.3 / 7.1-10.2	7.9 / 6.0-9.0	14.7 / 13.1-17.3	15.7 / 13.1-18.3
Spruce-subalpine fir forest (cover >35%)	7.3 / 6.0-8.2	5.9 / 4.0-9.2	10.6 / 6.0-13.2	9.8 / 4.0-13.2
Cloud shadow	6.2 / 4.0-8.1	4.7 / 4.0-12.2	4.5 / 3.0-6.1	2.9 / 1.0-4.0

TABLE 2. Euclidean distances between clusters from analysis of winter Landsat imagery (3 March 1977, #20771-17351) *

1	0.00	58.16	120.31	188.90	268.54	357.45
2	58.16	0.00	62.56	131.35	211.05	299.81
3	120.13	62.56	0.00	68.81	148.51	237.30
4	188.90	131.35	68.81	0.00	79.72	168.59
5	268.54	211.05	148.51	79.72	0.00	89.18
6	357.45	299.81	237.30	168.59	89.18	0.00

* Refer to text, section 3.3.

in bands 6 and 7 is seen between non-forested snow-free sites and sparse conifer forest and lodgepole pine-spruce forest cover types. No spectral overlap is seen between non-forest snow-free sites and spruce-subalpine fir forest and cloud cover.

In band 5, non-forested snow-free sites completely overlap the shrubland/conifer forest cover type. Partial and significant spectral overlap with the non-forested snow-free sites occurs for non-forested snow-covered sites, cloud, and cloud shadow. No overlap is seen between the non-forested snow-free sites and spruce-subalpine fir forest and cloud shadow.

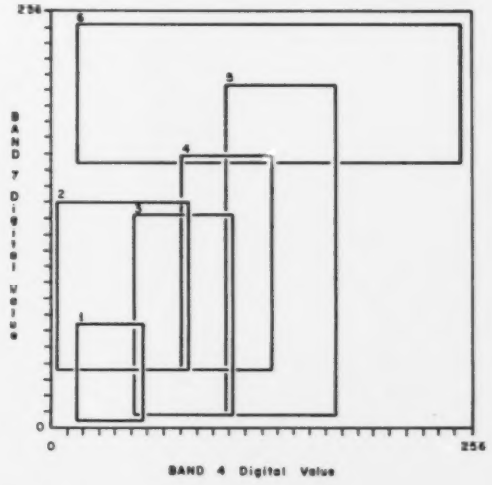
In band 4, the non-forested snow-free cover type significantly overlaps the following other cover types: clouds; shrublands; deciduous and mixedwood forests; sparse conifer forest; and lodgepole pine-spruce forest. Insignificant or no overlap is seen of non-forested snow-free sites over non-forested snow covered sites, over spruce-subalpine fir forest or over cloud shadow. If significant overlap in digital values exists between any two surface feature types for any band, those two features will be confused in any density slice which includes that area of overlap. As can be seen from the previous discussion, significant overlap in the digital values of the non-forested snow-free cover type is seen in each band for many of the major cover types found in the study area.

3.3 Multispectral Classification

Six clusters could be defined through unsupervised classification of the 3 March 1977 Landsat image. Table 2 lists the Euclidean distance measures between each cluster. Significant overlap and convergence is evident. Figure 3 indicates extensive overlap in digital values of most clusters in bands 4 and 7. Significantly lower spectral ranges exist for most clusters in bands 5 and 6 as shown on Figure 4.

If the clusters are to be recognizable and meaningful as surface feature types, they must accurately define distinct surface feature types. An analysis of the subject content of each cluster was made by comparing the scaled thematic map outputs of each cluster with detailed 1:60,000 scale color infrared imagery of the area mapped. Significant heterogeneity was found in each cluster.

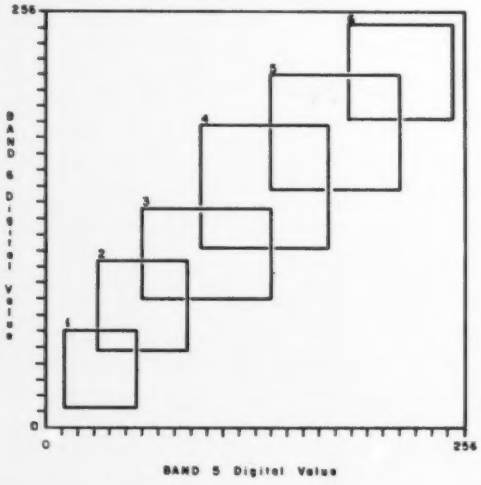
Cluster 3 includes the important non-forested snow-free sites. However, also included in this cluster are features such as deciduous woodlands with snow cover in the understory, mixed woodlands, spruce forest with snow cover in the understory and/or on the foliage, shrublands with understory snow cover and sparse coniferous forest sites. Clusters 1, 2, 4, 5 and 6 included all shadowed areas, spruce subalpine fir forest, Douglas-fir forest,



Upper and Lower Bound Limits of Clusters
(256 Spectral Resolution Scale)

Cluster	Band 4	Band 7
1	16 to 56	4 to 64
2	4 to 84	36 to 140
3	52 to 112	8 to 132
4	80 to 136	36 to 168
5	108 to 176	8 to 212
6	16 to 252	164 to 252

Figure 3 Cluster bounds for vegetation cover types identified on Landsat imagery (3 March, 1977). Band 4 vs Band 7.



Upper and Lower Bound Limits of Clusters
(256 Spectral Resolution Scale)

Cluster	Band 5	Band 6
1	12 to 56	12 to 60
2	32 to 88	48 to 104
3	60 to 140	80 to 136
4	96 to 176	112 to 188
5	140 to 220	148 to 220
6	188 to 252	192 to 252

Figure 4 Cluster bounds for vegetation cover types identified on Landsat imagery (3 March, 1977). Band 5 vs Band 6.

Fig. 5a The orange area is the South Sheep River grazing allotment study area.

Fig. 5b The pseudocolors represent various forest cover types automatically classified and mapped using the 25 September, 1979 Landsat image.

Figure 5 The South Sheep River grazing allotment showing the sequential steps required for mapping non-forested snow-free sites. (Refer to text, section 3.4, page 9).

Fig. 5c Automatic computer mapping (blue area) of sncw cover 8 April, 1979.

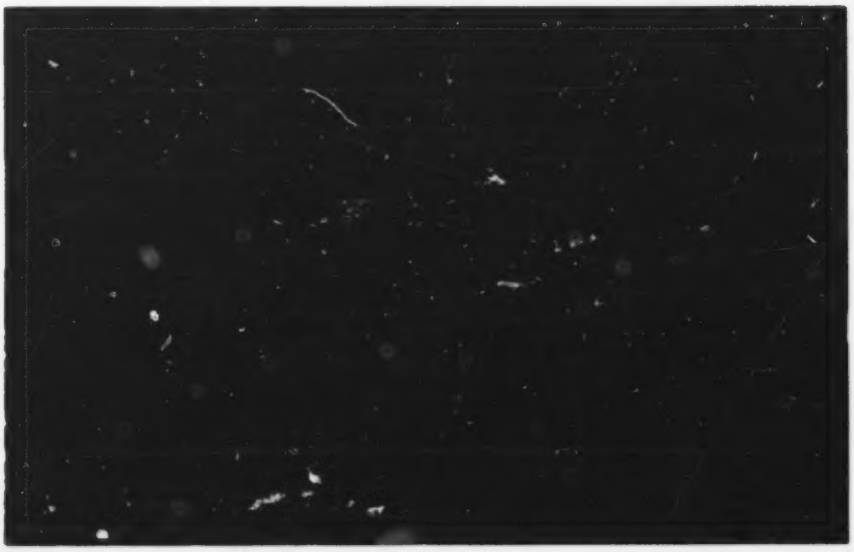


Fig. 5d Non-forested snow-free sites (yellow area) on 8 April, 1979.

spruce forest, mature lodgepole pine forests on south slopes and spruce-aspen woodlands. Cluster 3 includes all non-forested snow-free areas, aspen woodlands with snow in the understory, spruce woodlands with snow in the understory, shrublands with a mosaic of small snow-free grassland sites, and sparse coniferous forest (crown closure > 20% and < 45%) with snow cover. Cluster 4 includes non-forested continuously snow-covered sites which are level or nearly so (slopes 0° to 10°). Cluster 5 includes continuously snow covered non-forested sites with aspects between south-south-west and north (190° to 360°). This includes all savanna coniferous forest sites with a canopy closure of less than 20%. Cluster 6 includes continuously snow covered non-forested sites with a generally east-facing aspect (i.e. 0° to 190° azimuth).

The errors of commission for identification of non-forested, snow-free sites were approximately 42% using this multispectral classification method. Of sixty sites mapped as cluster #3, twenty-five were features other than the desired non-forested, snow free sites. The majority of the confusion was between these sites and deciduous woodlands with snow cover in the understory and sparse conifer forests with snow cover in the understory.

3.4 Multitemporal Landsat Analysis

Figure 5 shows the results of the computer classification of the summer Landsat scene and the winter Landsat scene. Figure 5A shows the electronically-cursored boundary of the South Sheep River grazing allotment. This area was used as the study area.

Figure 5B shows the distribution of the vegetation types classified on the summer Landsat image. Eight clusters were identified and mapped throughout the South Sheep River study area. The generalized descriptions of each cluster are as follows: spruce-subalpine fir forests on northeast to northwest aspects; spruce-subalpine fir forests on all other aspects; lodgepole pine and pine-spruce-fir forests; mixedwood forests; aspen woodlands; grasslands; rocklands on northeast to northwest aspects; and rocklands on southeast to southwest aspects.

Figure 5C shows the distribution of snow cover on the 8 April 1979 Landsat image. These areas are largely alpine and grassland, but also include forests with enough snow in the understory or on the foliage to classify as snow-covered on this Landsat scene. In Figure 5C the snow-cover classification theme from the winter image has been overlayed onto the summer Landsat image following geometric registration of the two Landsat images.

Figure 5D shows the location of non-forested snow-free sites which existed on the South Sheep River grazing allotment on 8 April, 1979. These sites are shown in yellow throughout the allotment.

An 89% accuracy was obtained for mapping of "non-forested snow-free" sites using this multitemporal analysis method. Table 3 shows the results of the commission error analysis. Pixels accurately classified as "non-forested, snow-free" sites (with < 15% forest canopy closure) amounted to 84.3% of the total area occupied by the 366 pixels studied. If "non-forested, snow-free" sites which possess only 15-35% forest cover are treated as "non-forested" the classification accuracy increases to 88.6%.

These non-forested snow-free sites are located on south to southwest facing slopes or ridgetops. They are concentrated east of the confluence of Gorge Creek with the Sheep River. Many of these sites are known to be used by wintering ungulates (Wishart 1958) and form critical winter habitat for these animals.

4. CONCLUSIONS

Visual interpretation of non-precision-processed Landsat images can be used to map large non-forested snow-free areas in the Fescue Grassland Ecoregion of Alberta. In the Aspen Parkland and Subalpine ecoregions significant confusion exists between non-forested snow-free sites and various forested sites with or without snow cover. Visual interpretation accuracy of mapping these non-forested snow-free sites was shown to be only 64%.

Single date computer analysis of winter Landsat images provided mapping of non-forested snow-free sites at similar low accuracies. Fifty-two percent of the sample sites identified as non-forested snow-free were actually forested sites with snow cover. These single date analyses included density slicing of each of the four Landsat bands and multispectral cluster analysis using an unsupervised classification algorithm.

Most errors in either visual or single date digital identification occur on sites that are deciduous or mixed deciduous-conifer forests and possess snow cover in the understory or on their foliage. Conifer forests with snow cover are also often confused with non-forested snow-free sites, using the multispectral bands available on Landsat satellites. Omission errors also probably exist with bare limestone and dolomite rocklands which possess spectral characteristics similar to sites covered with snow. The magnitude of these omission errors could not be evaluated in this study.

A multidate approach to identification of non-forested snow-free sites provided a classification accuracy of 89%. This computer mapping technique, which uses both a summer and a winter Landsat scene, provides accurate and rapid mapping of potential critical winter range sites for native ungulates. No other practical method exists for obtaining this type of wildlife habitat information.

TABLE 3. Accuracy of multitemporal Landsat digital analysis for mapping non-forested winter snow-free sites in the Rocky Mountains of Alberta.

Cover Type*	Area (ha)	# of Sites	% of Sites	% of Area
Non-forested sites	1503.0	366	78.5	84.3
1b 341	2.6	2	0.4	0.1
2b 341	11.3	9	1.9	0.6
2b 341.1	13.6	6	1.4	0.8
2b 341.3	17.7	7	1.6	1.0
1b 341.6	2.9	1	0.2	0.2
2b 341.7	7.0	2	0.4	0.4
1b 341.8	6.6	1	0.2	0.4
1b 342	0.8	1	0.2	0.1
2b 342	6.3	2	0.4	0.3
3b 342	3.6	2	0.4	0.2
2b 343	1.1	1	0.2	0.1
2b 343.1	1.2	1	0.2	0.1
Subtotal (non-forested snow-free plus all "b" density classes)	1577.7	401	86.0	88.6
2c 341	11.5	3	0.6	0.6
2c 341.1	6.8	3	0.6	0.4
3c 341.1	1.0	1	0.2	0.1
2c 341.3	13.7	4	0.9	0.8
2c 343	58.5	13	2.8	3.2
1c 342	9.0	2	0.4	0.5
2c 342	9.9	5	1.2	0.6
Subtotal (non-forested snow-free plus all "b" and "c" density classes)	1688.1	432	92.7	94.8
Total	1782.3	466	100.0	100.0

*Legend for cover types:

1	b	341
Height Class	Canopy Closure Class	Forest Composition

Height Classes (meters: 1 = 0-8; 2 = 9-15; 3 = 16-25.

Canopy Closure Classes (%): 0 = 0-5; a = 6-15; b = 16-35; c = 36-65; d = 66-85; e =>85.

Forest Composition:
- 341 = Conifer dominated Forest
- 341.1 = Lodgepole pine - dominated
- 341.3 = Spruce - dominated
- 341.6 = Subalpine fir - larch - dominated
- 341.7 = Larch - dominated
- 341.8 = Subalpine fir - dominated
- 342 = Deciduous forest
- 343 = Deciduous - conifer mixed forest
- 343.1 = Aspen - Spruce mixed forest

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